Numerical Simulations of Large-Scale CO_2 Injection Incorporating Effect of Potential Wellbore Leakage

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What is this talk about?

- At-scale implementation of CCS would require injection of large volumes of CO_2
- Detailed numerical simulations of CO_2 injection and subsequent migration will be an integral part of long-term performance prediction process
  - One measure of performance will be the system response with cemented/leaking wellbores

Coupled wellbore-reservoir flow simulations for CO_2 storage (I)

- Need to understand and characterize behavior of wellbores during and after injection of large volumes of CO_2
  - Migration through wellbore is dependent on dynamic evolution of near-wellbore conditions including cement degradation
  - Need to effectively & efficiently capture wellbore details including geometry, completions and radial nature of flow
  - Need to simultaneously simulate large-scale reservoir flow

- Princeton (Mike Celia group) has proposed a semi-analytical model for injection in reservoir and migration through plugged wellbores (Nordbotten et al)

Coupled wellbore-reservoir flow simulations for CO2 storage (II)

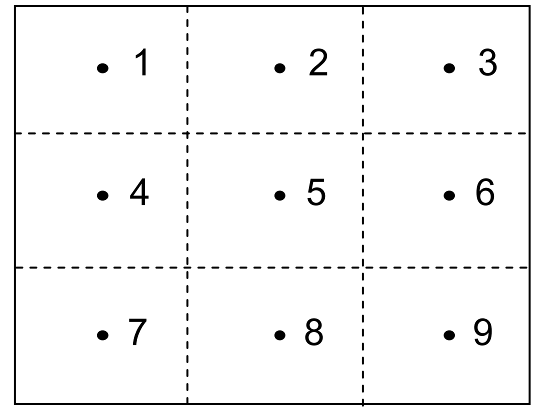
- Traditional approaches to represent detailed wellbores in numerical reservoir simulators have limitations
  - Peaceman approximation:
    - Can not effectively capture near well bore conditions
  - Grid refinement & hybrid grid approaches:
    - Limited flexibility (need a priori knowledge of wellbore location)
    - Require significant effort in re-gridding
    - Usually result in large computational grids

FEHM & its novel wellbore incorporation approach

- Finite Element Heat & Mass (FEHM) numerical simulator
  – Multi-dimensional, multi-phase porous media heat & mass transfer simulator (brine,water, CO_2, methane hydrates)
  – Coupled flow, reactive transport, and stress capabilities
  – Extensively used in ground-water flow-reaction simulations
  – Finite volume method captures complex geology
  – A novel approach to incorporate wellbores
    - Flexible addition of wellbores to an existing grid
    - Radial representation of wellbore at any desired spatial resolution in a coarser, 3-D grid
    - Computationally efficient simulation of short-term and long-term near wellbore processes

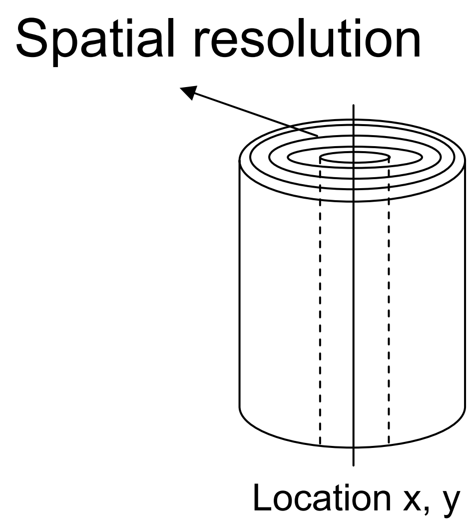
How does the wellbore incorporation algorithm work?

Create the primary reservoir grid (prior to creating input file or in the input file)



Define the wellbore in the input file:

- Specify wellbore location (x,y), wellbore radius
- Specify desired spatial resolution (radial in wellbore vicinity, vertical in the wellbore)
- Specify desired wellbore flow physics



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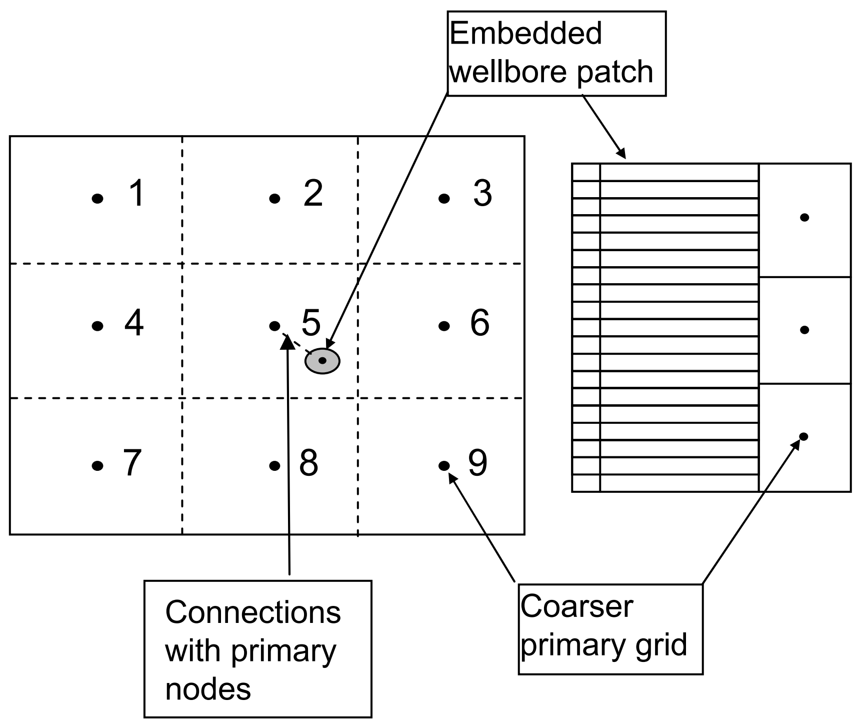
Wellbore incorporation algorithm continued

Embed the wellbore in primary grid:

The code identifies connections, modifies resistance terms, adjusts node control volumes



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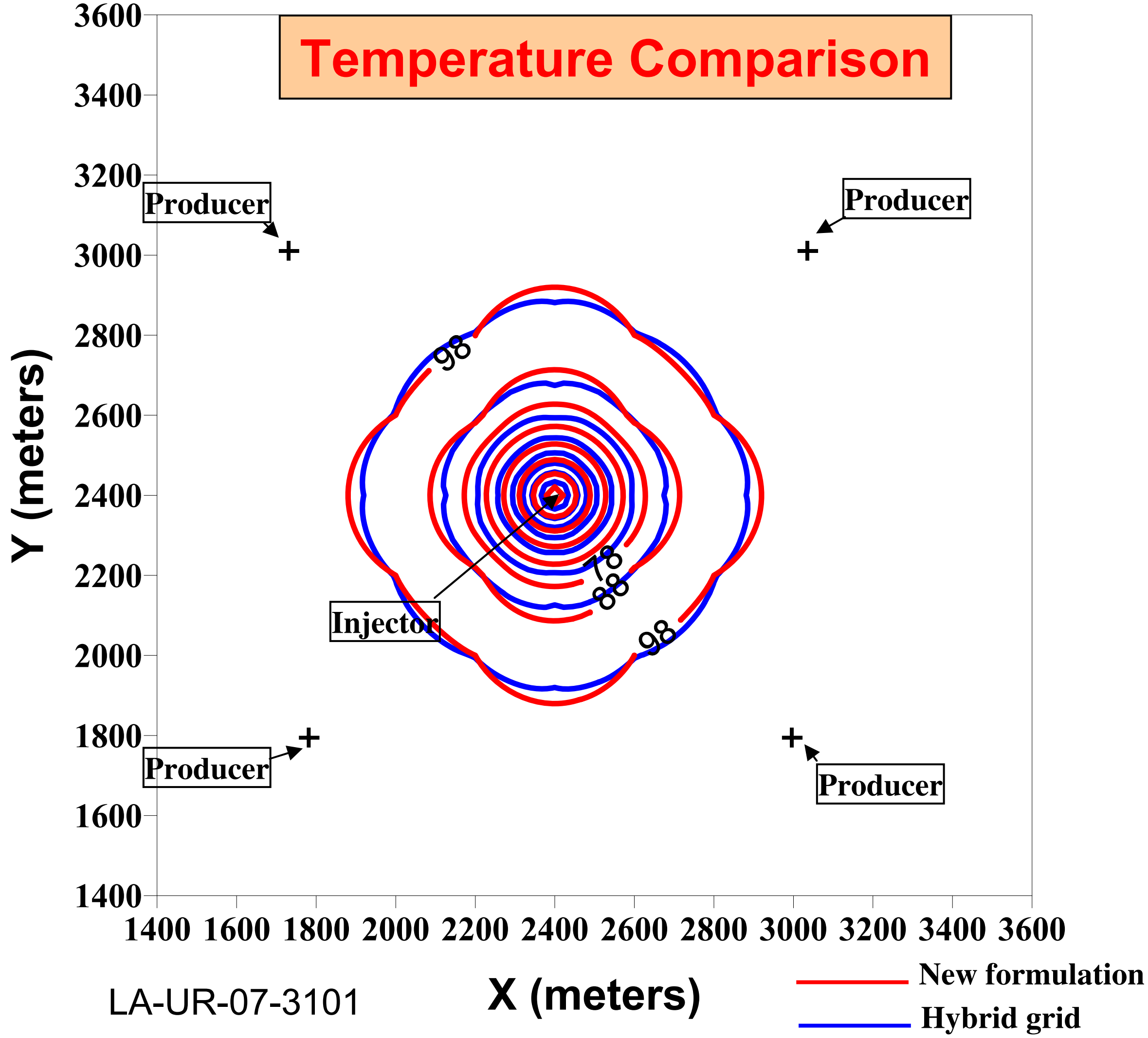
Comparing temperature predictions

Computational Times

Hybrid grid – 241 sec

New algorithm – 202 sec



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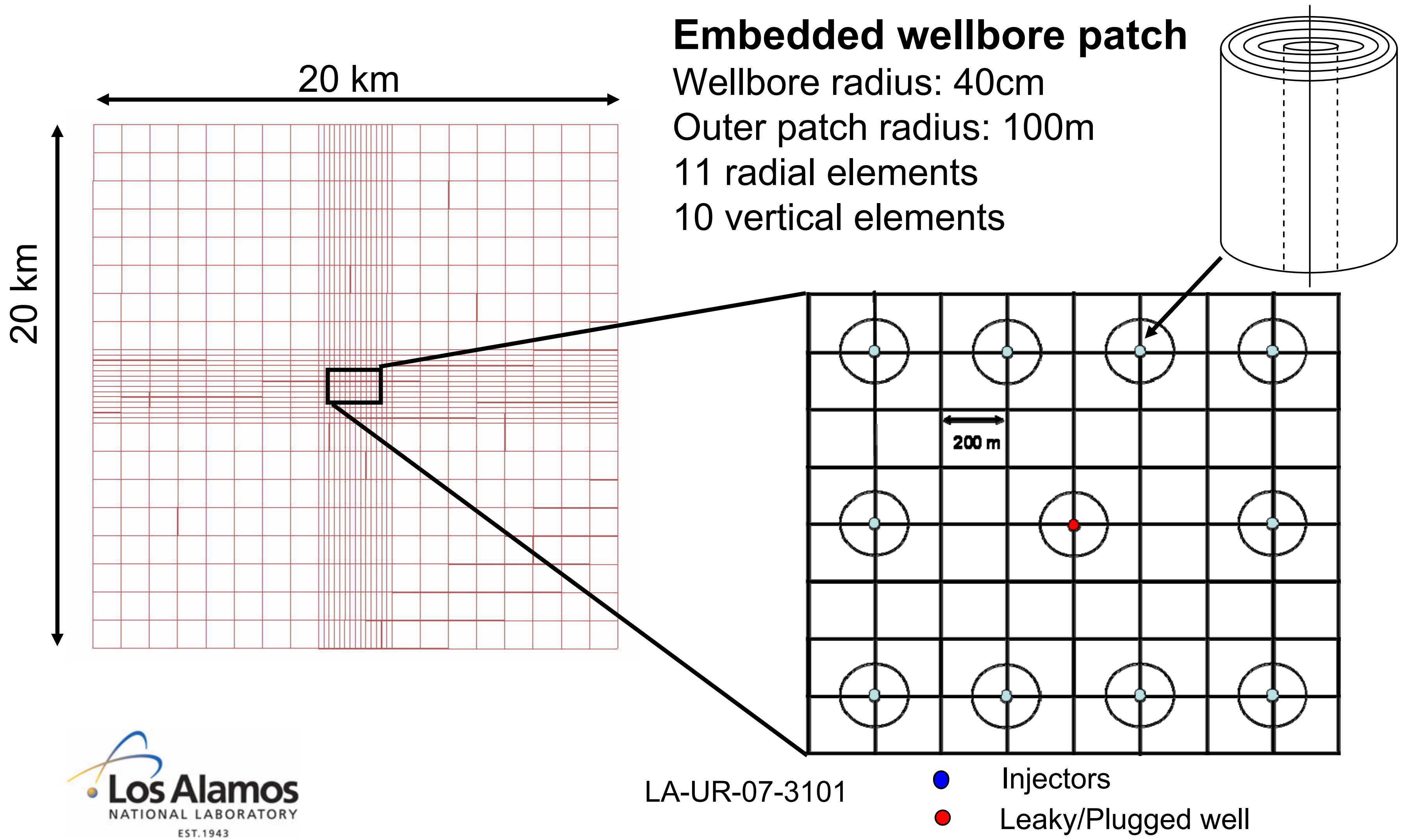
Large-scale CO_2 injection: problem definition

- Inject output for a 300 MW power-plant for 50 years
- 10 injectors @ 480 tons/day
- Base case: Permeability: 10^{-13} m^2 (100 mD), porosity = 0.2
- A leaky/plugged well in the center of injectors
- Cement permeability varied (10^{-10} - 10^{-16} m^2), Base case permeability 10^{-10} m^2
- Reservoir corners are water extraction wells at fixed P=20 MPa

Goal: Characterize amount of CO_2 leaving through plugged wellbore under a variety of parameters

Grid with wellbores: plan view

Embedded wellbore patch
Wellbore radius: 40cm
Outer patch radius: 100m
11 radial elements
10 vertical elements



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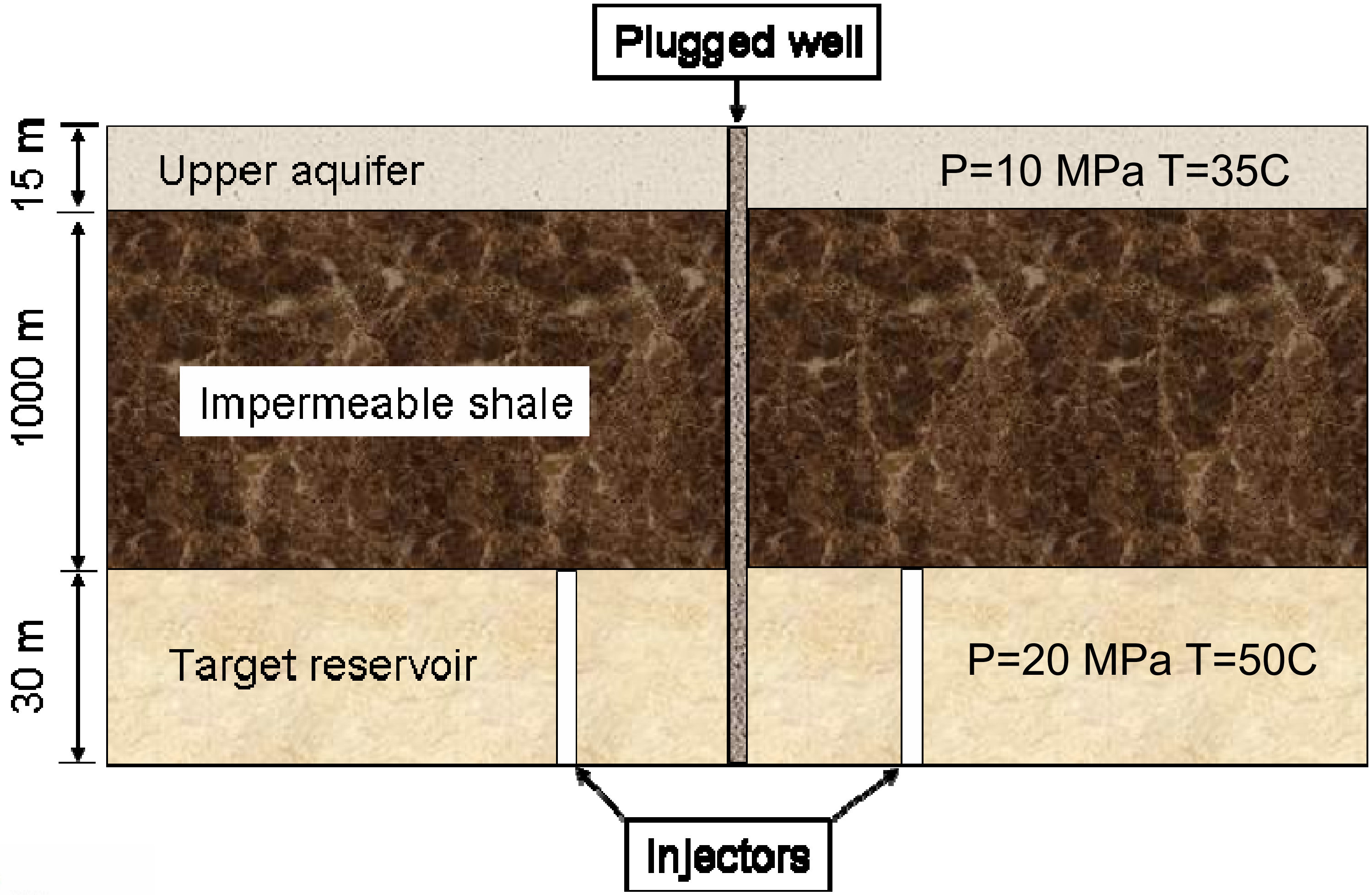
Schematic with wellbores in vertical direction



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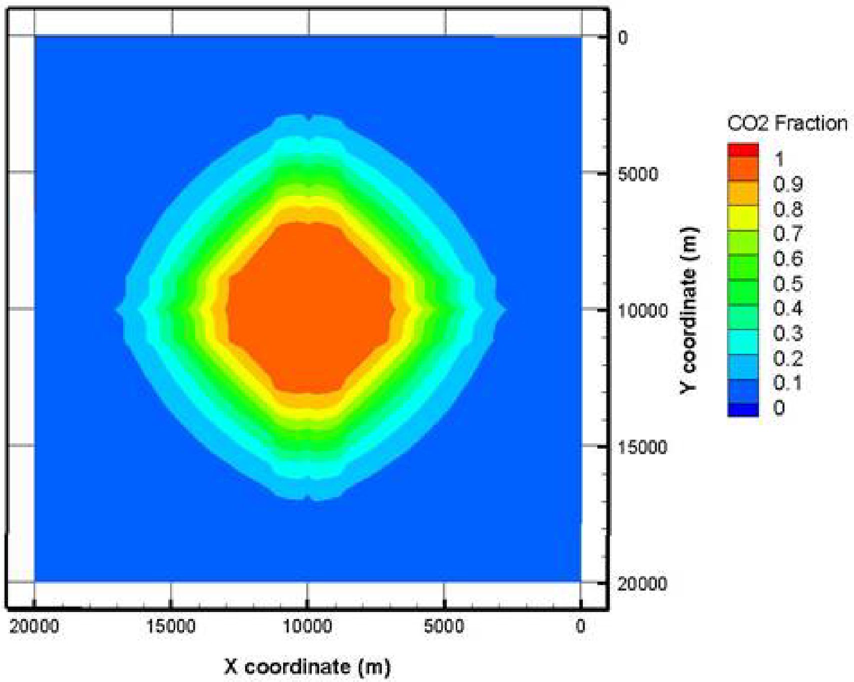
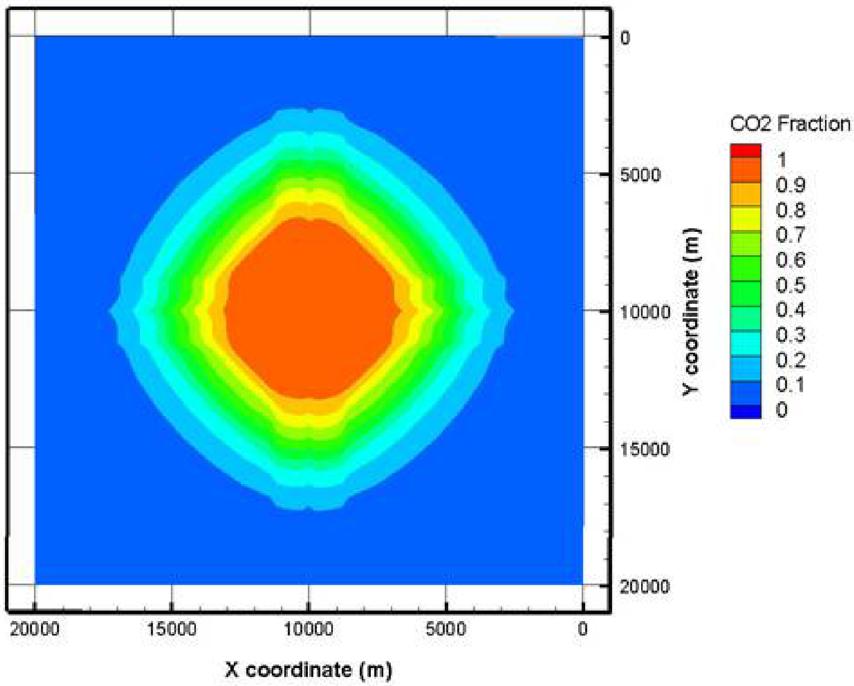
CO_2 plume in the reservoir (Base Case)

50 years



100 years



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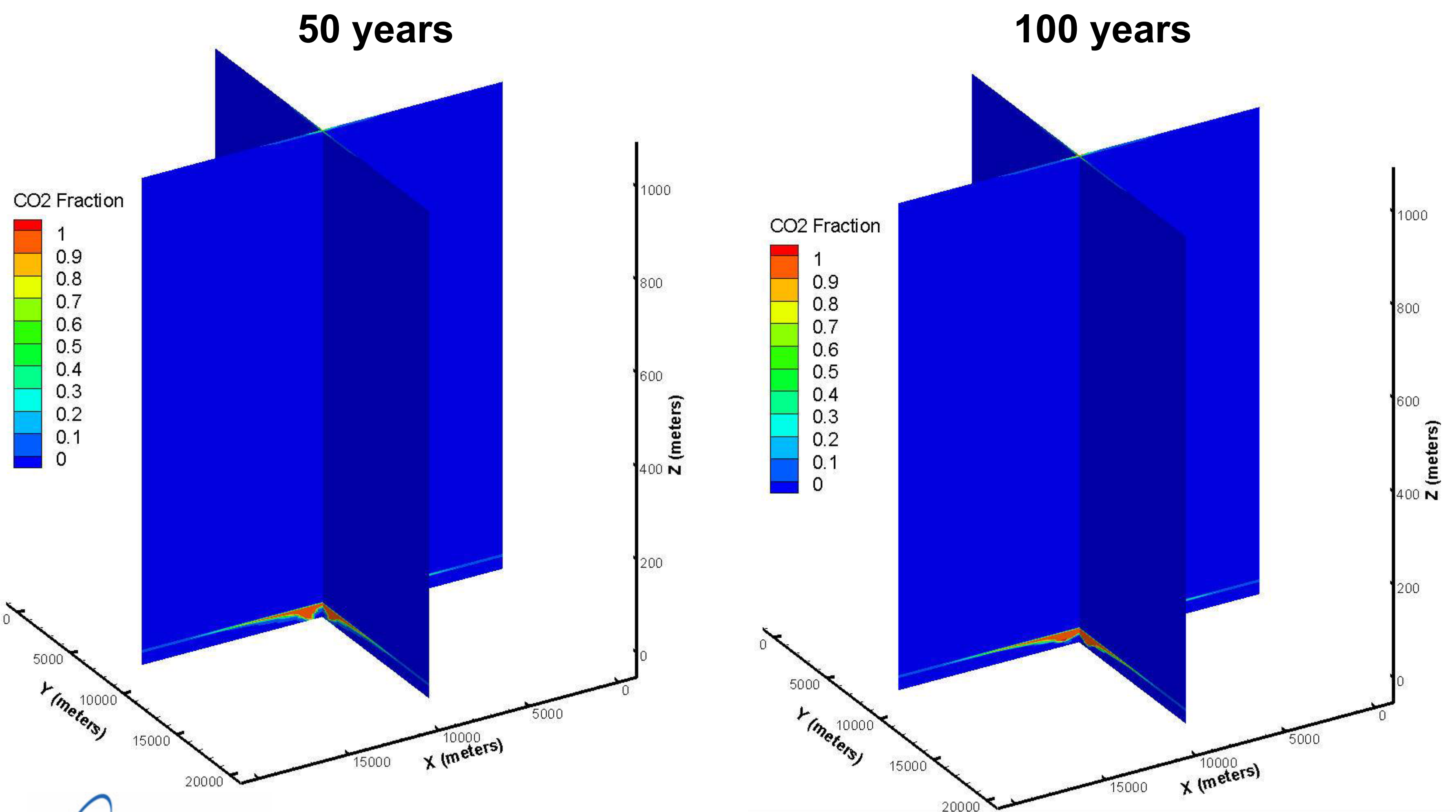
CO_2 plume : X-sectional view (Base Case)



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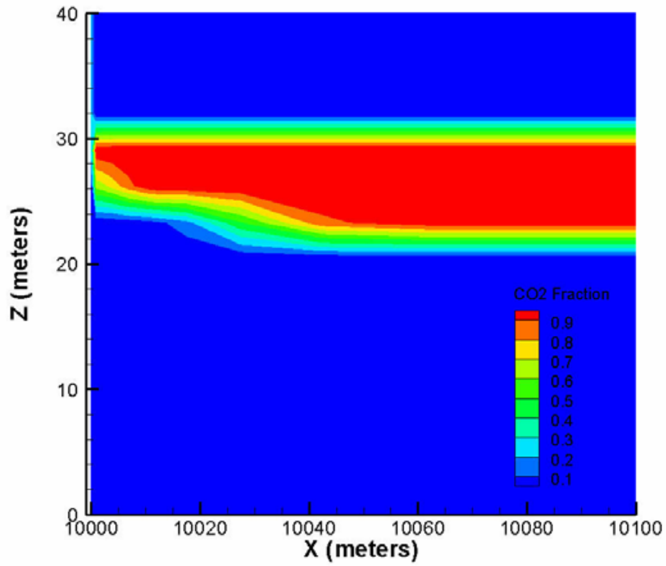
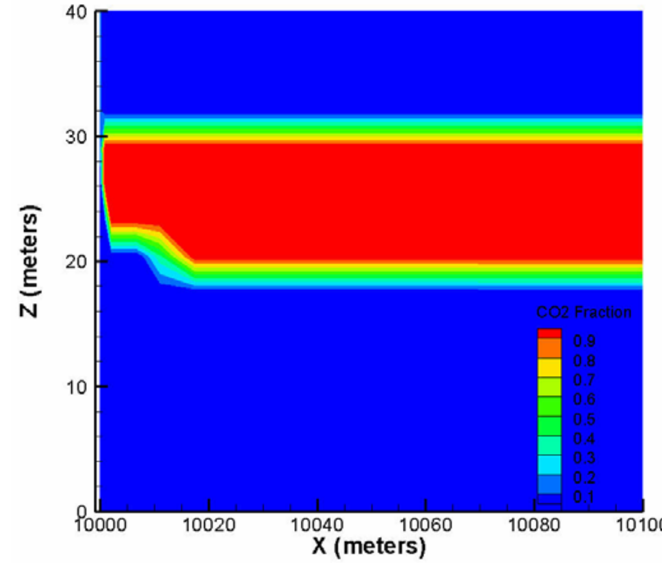
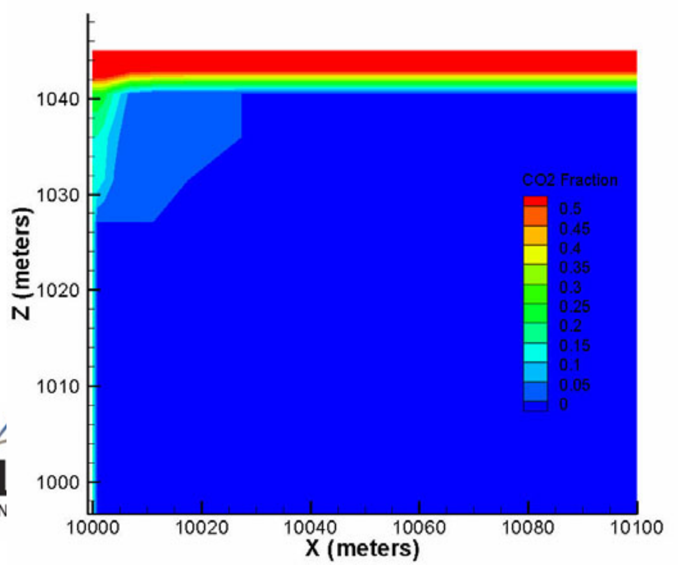
CO_2 fraction near wellbore (Base Case)

50 years | **100 years**

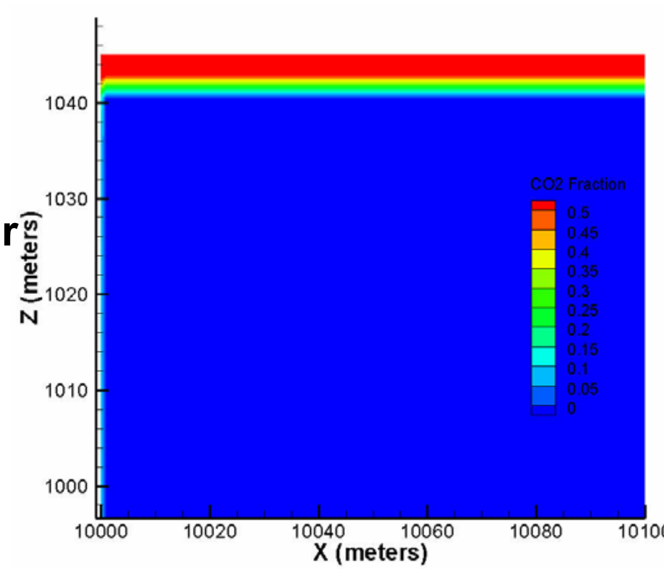


In reservoir



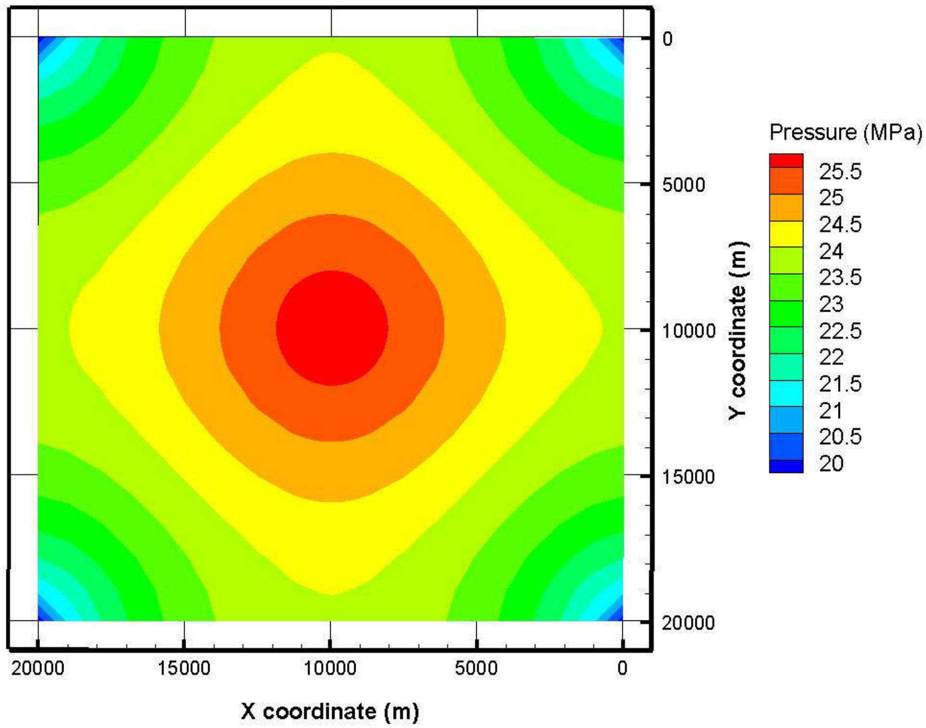


In top aquifer

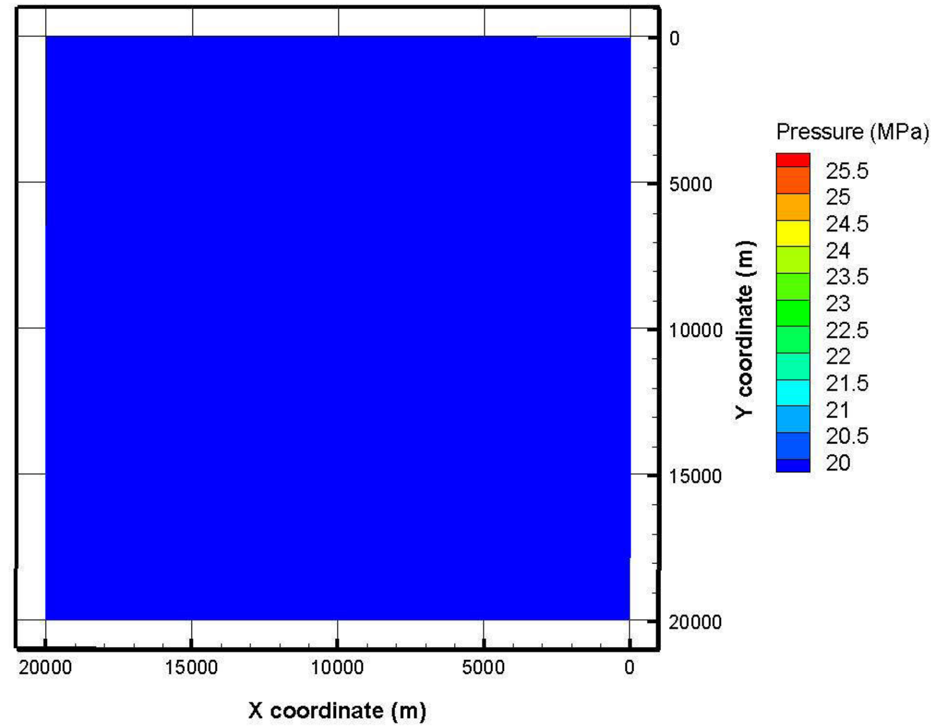


Pressure distribution in reservoir (Base Case)

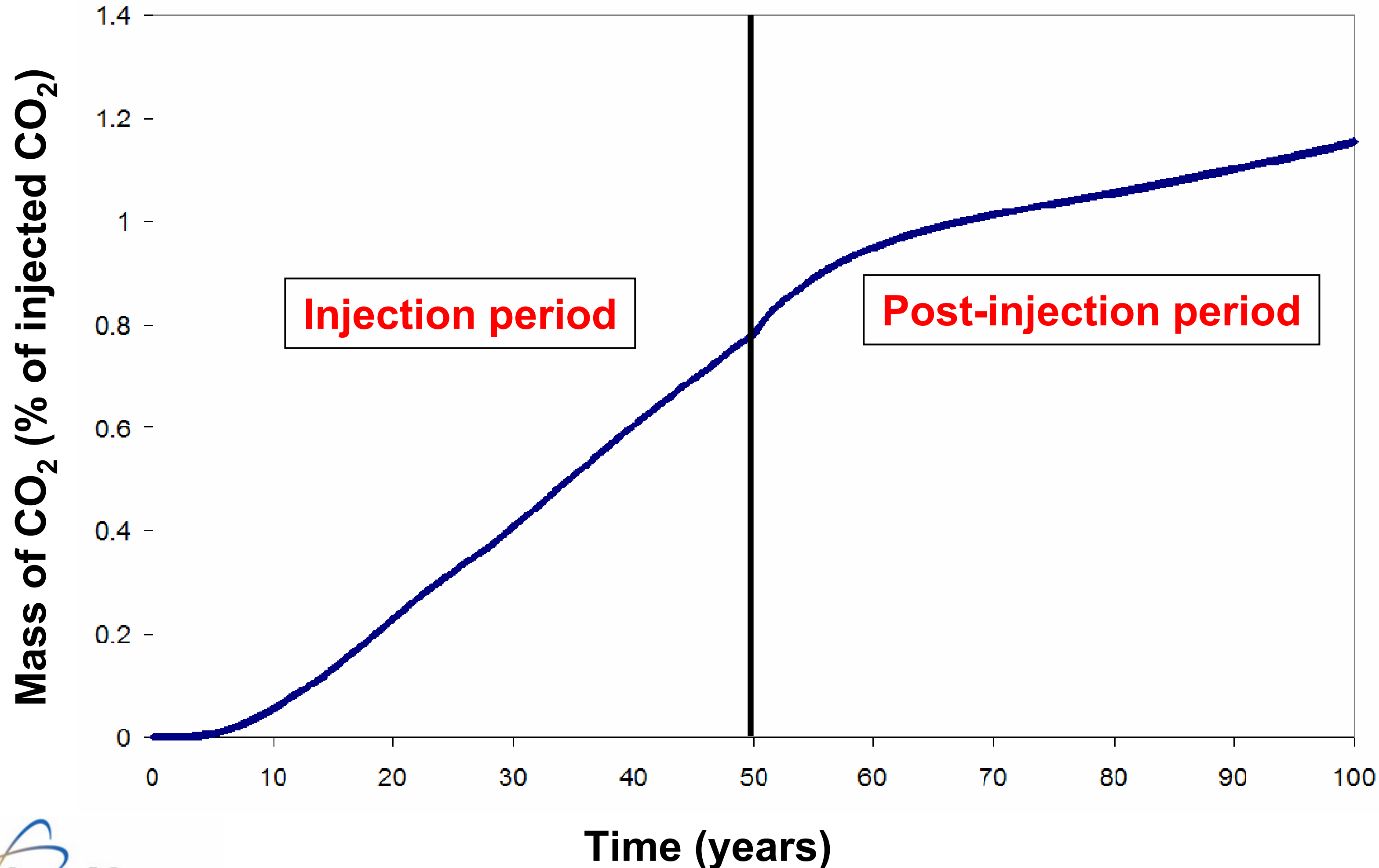
50 years



100 years



Mass of CO_2 in upper aquifer (Base Case)



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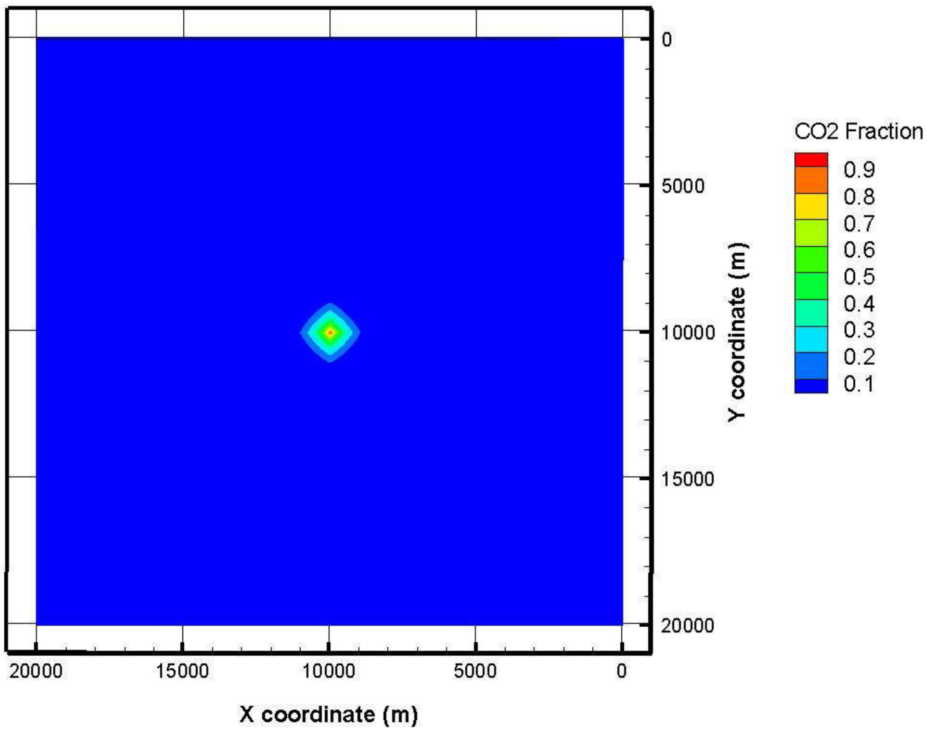
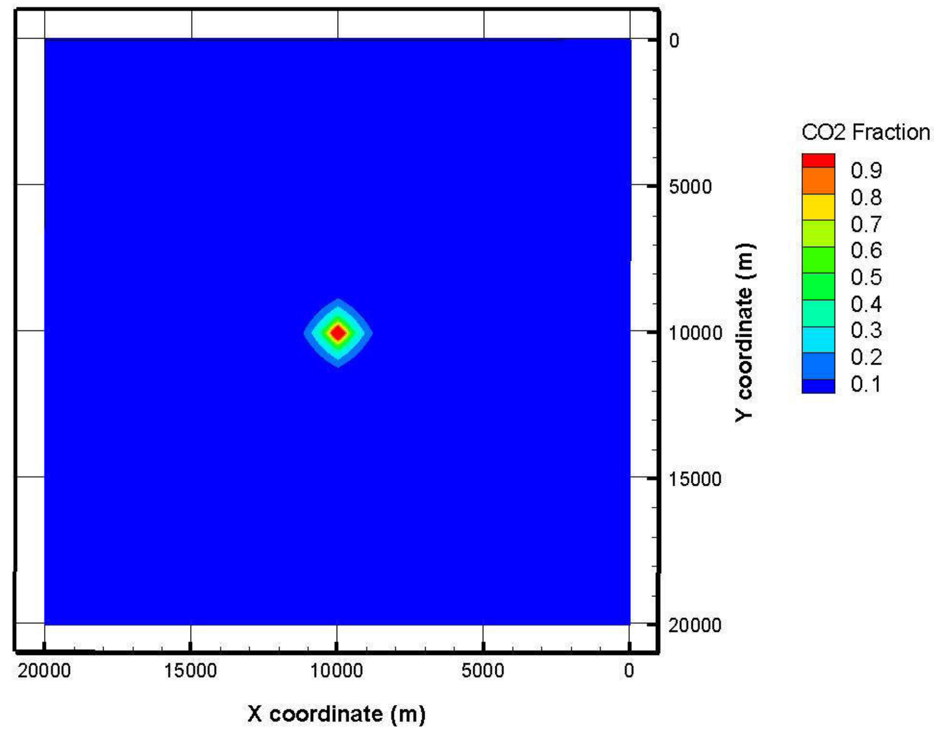
Total CO_2 injected in 50 years: ~ 87.6 million tons

CO_2 plume in the upper aquifer (Base Case)

50 years



100 years



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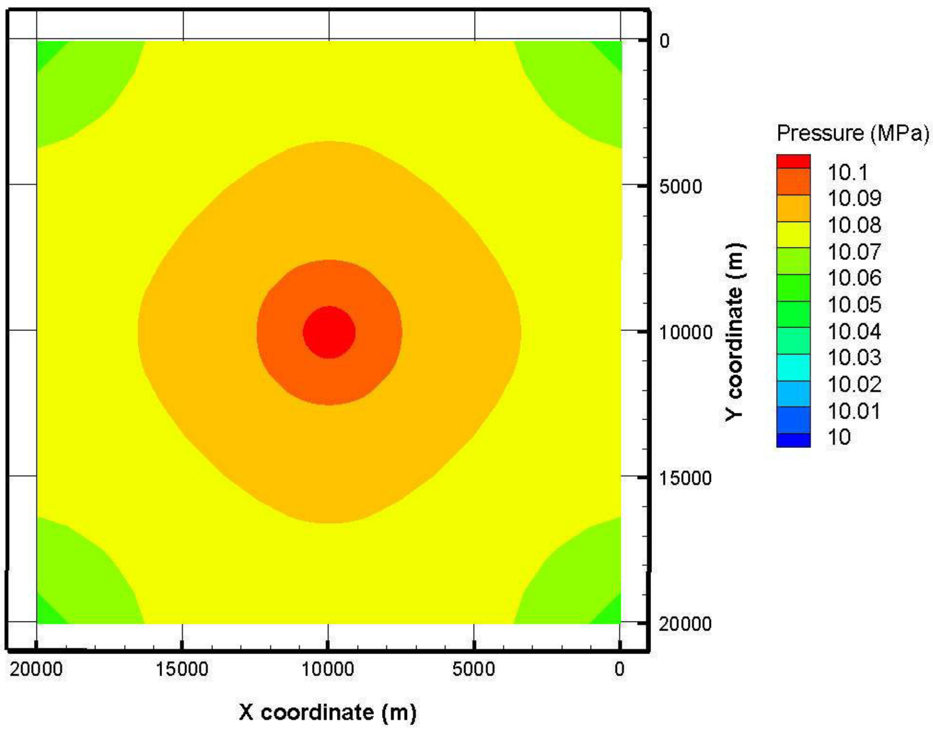
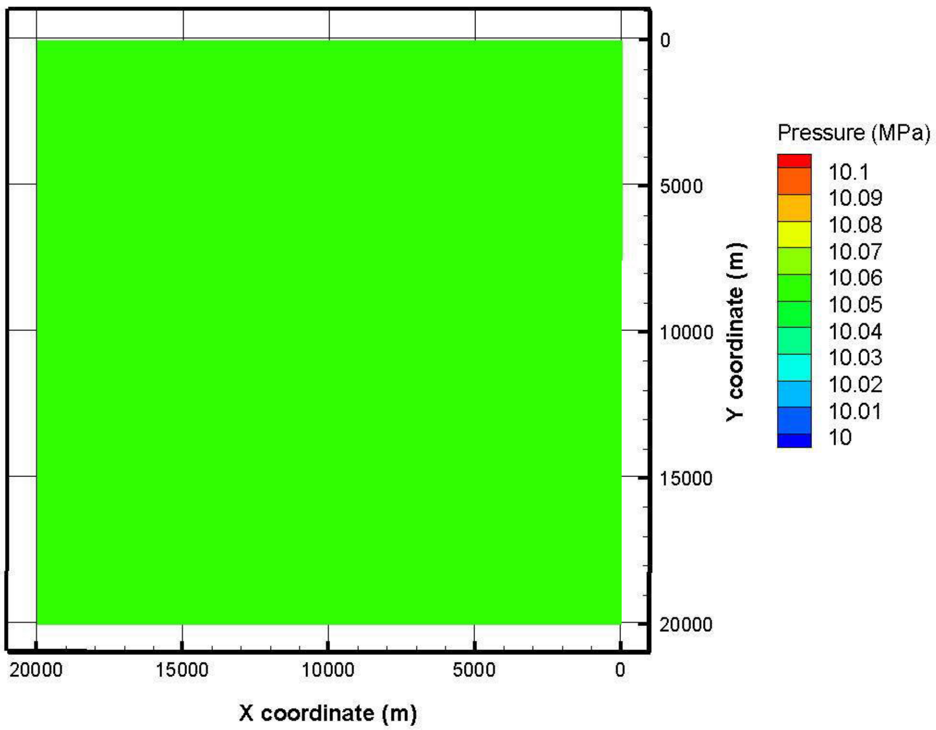
Pressure distribution in upper aquifer (Base Case)

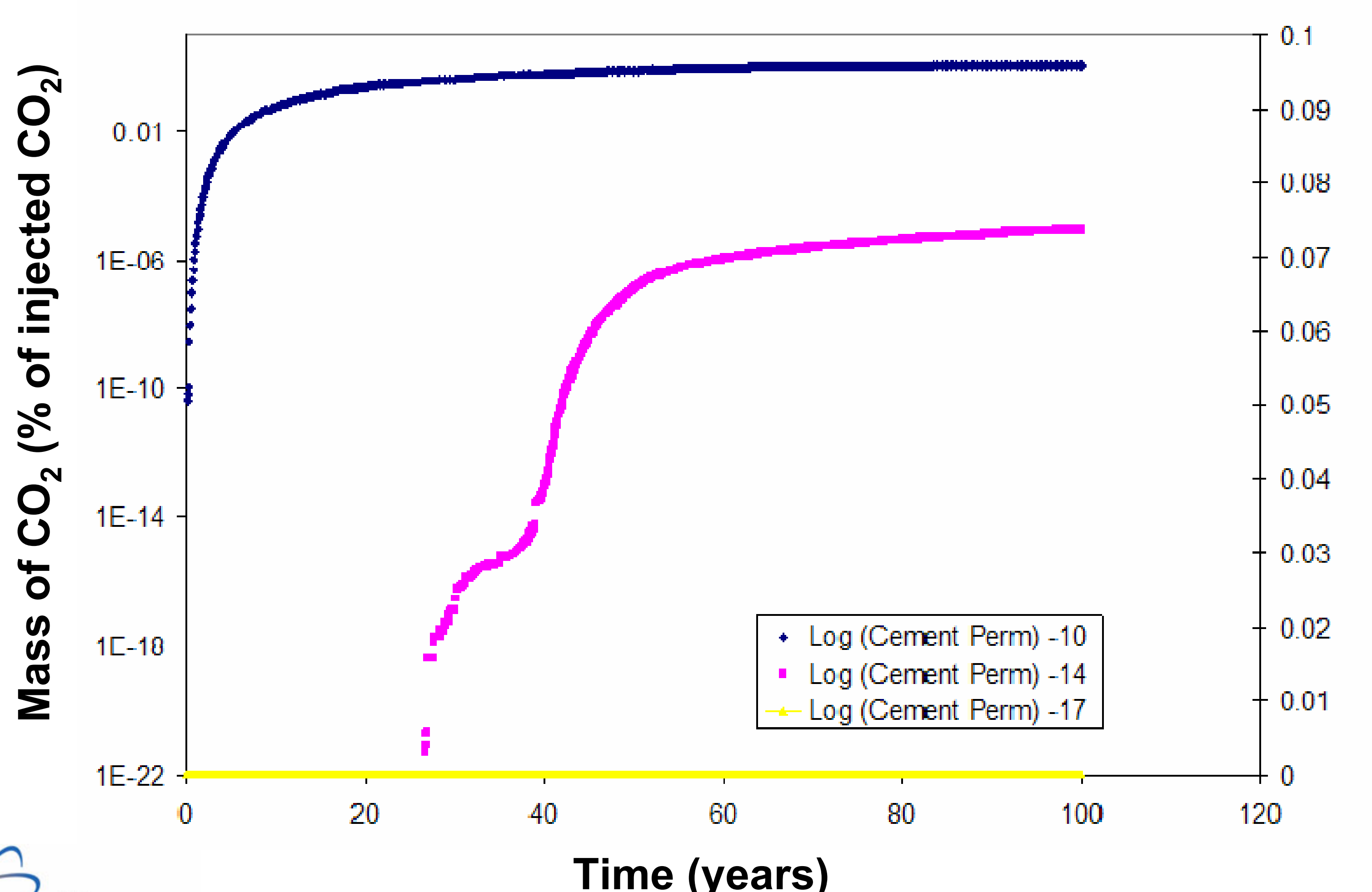
50 years



100 years



Effect of wellbore cement permeability on mass of CO_2 in top aquifer



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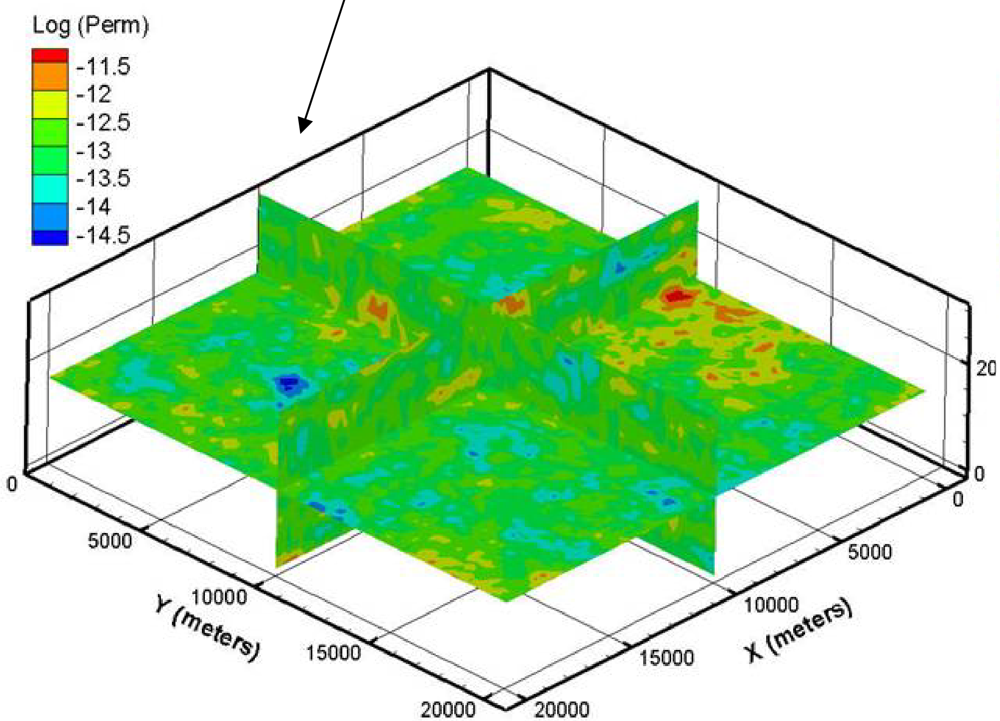
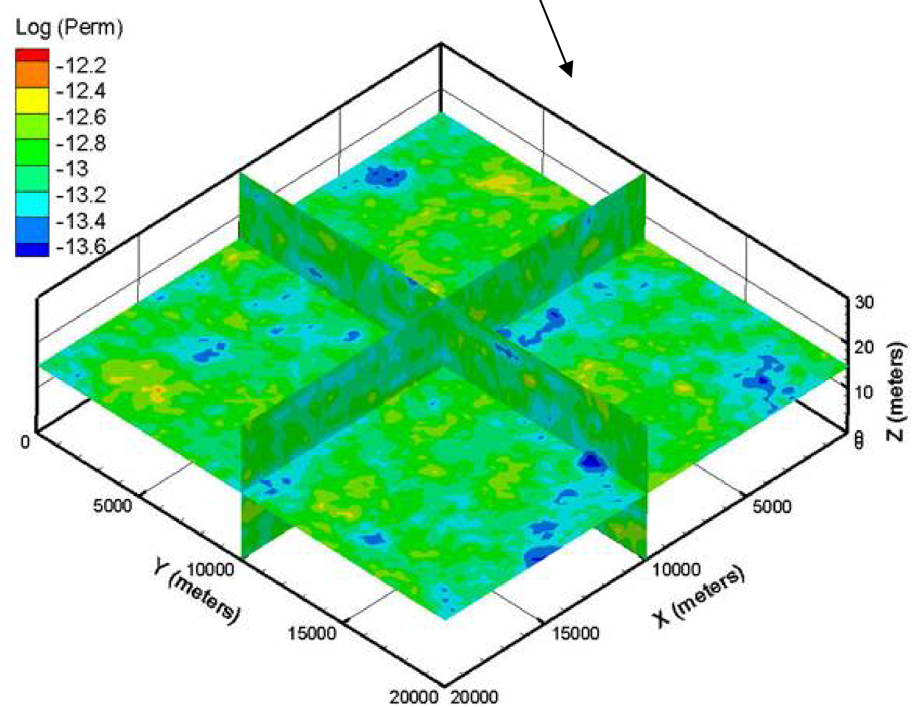
Effect of reservoir permeability heterogeneity

4 Cases

Mean Log (Perm): -13, Variance Log (Perm): 1
Mean Log (Perm): -13, Variance Log (Perm): 0.2
Mean Log (Perm): -14, Variance Log (Perm): 1
Mean Log (Perm): -14, Variance Log (Perm): 0.2

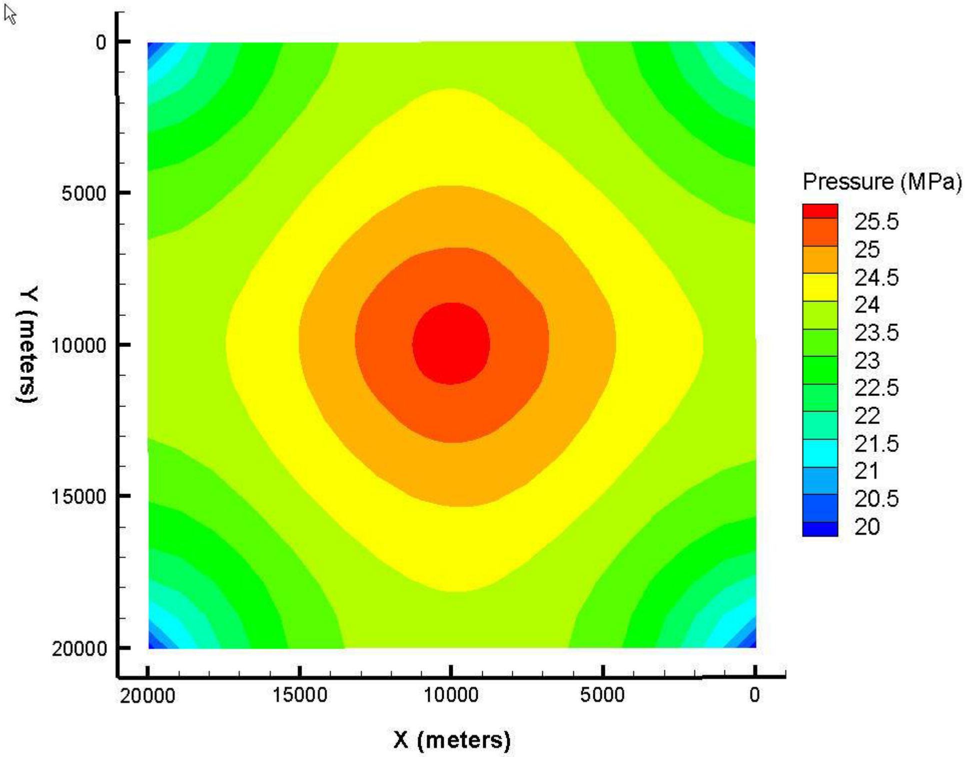




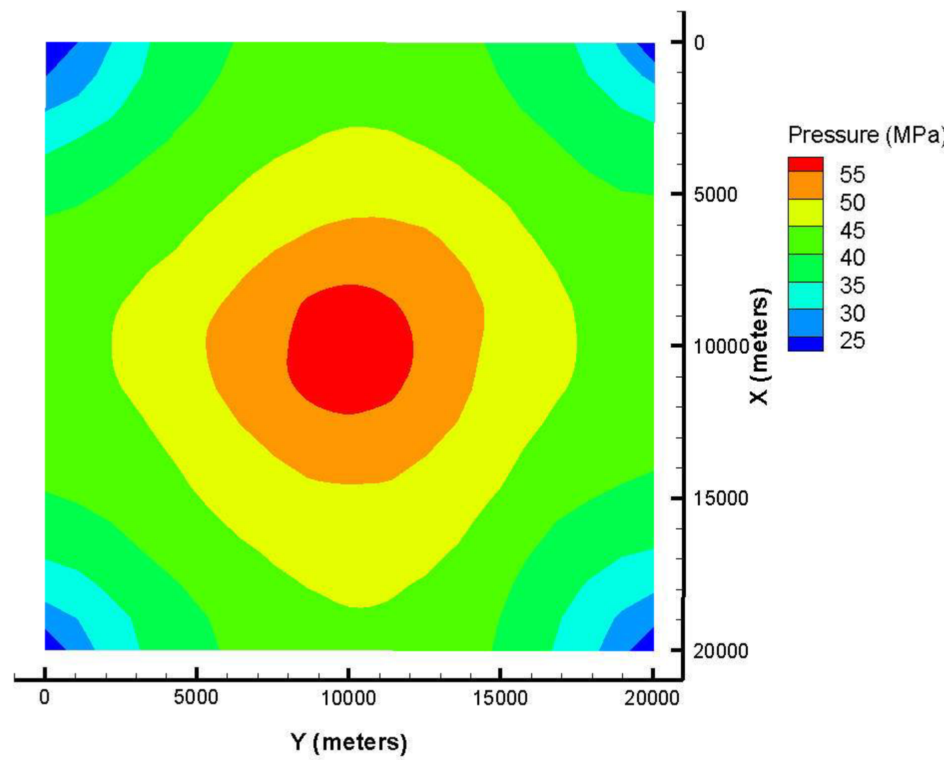
Correlation Length (x & y) : 1000m
Correlation Length (z) : 15m

Reservoir Pressure Distribution (50 years)

Mean Log (Perm): -13,
Variance Log (Perm): 1

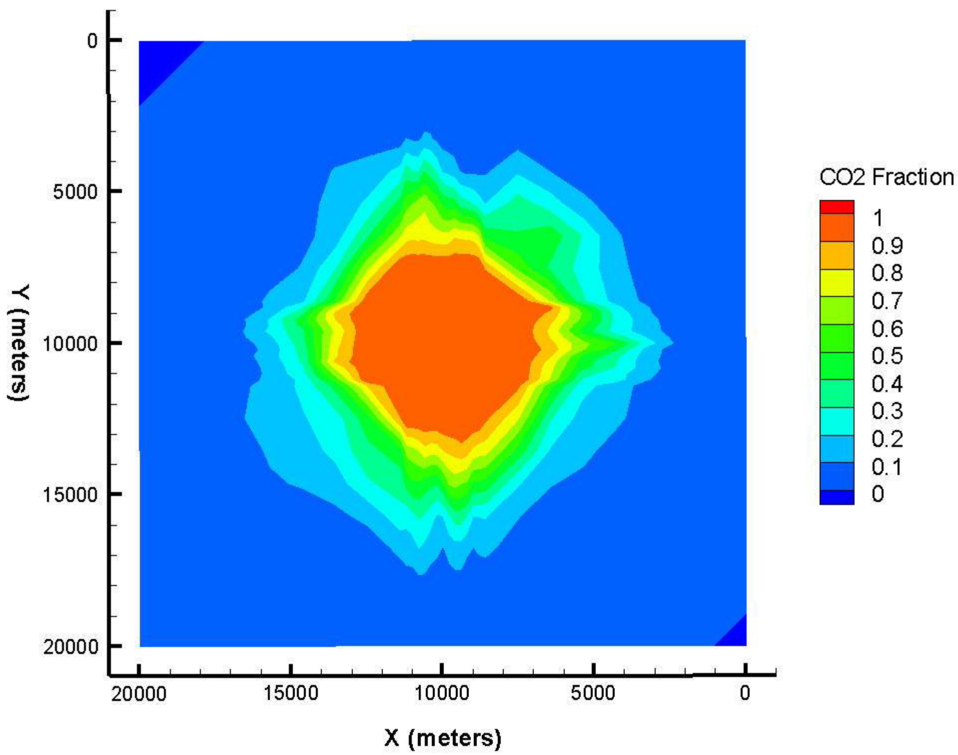


Mean Log (Perm): -14,
Variance Log (Perm): 0.2

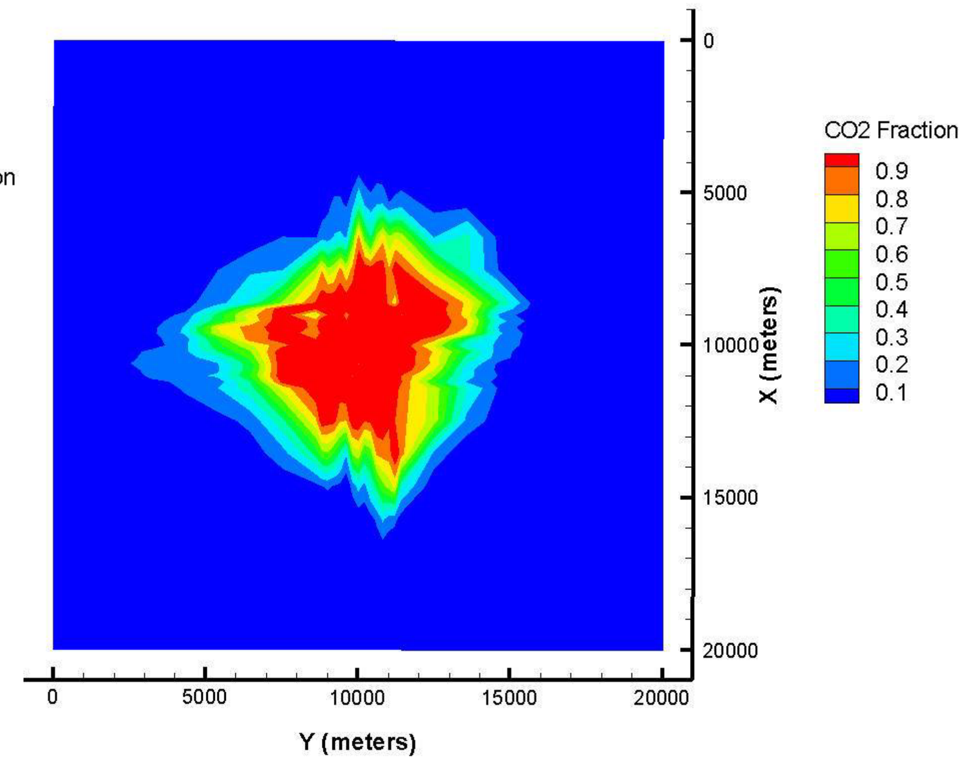


Reservoir CO_2 Distribution (50 years)

Mean Log (Perm): -13,
Variance Log (Perm): 1



Mean Log (Perm): -14,
Variance Log (Perm): 0.2



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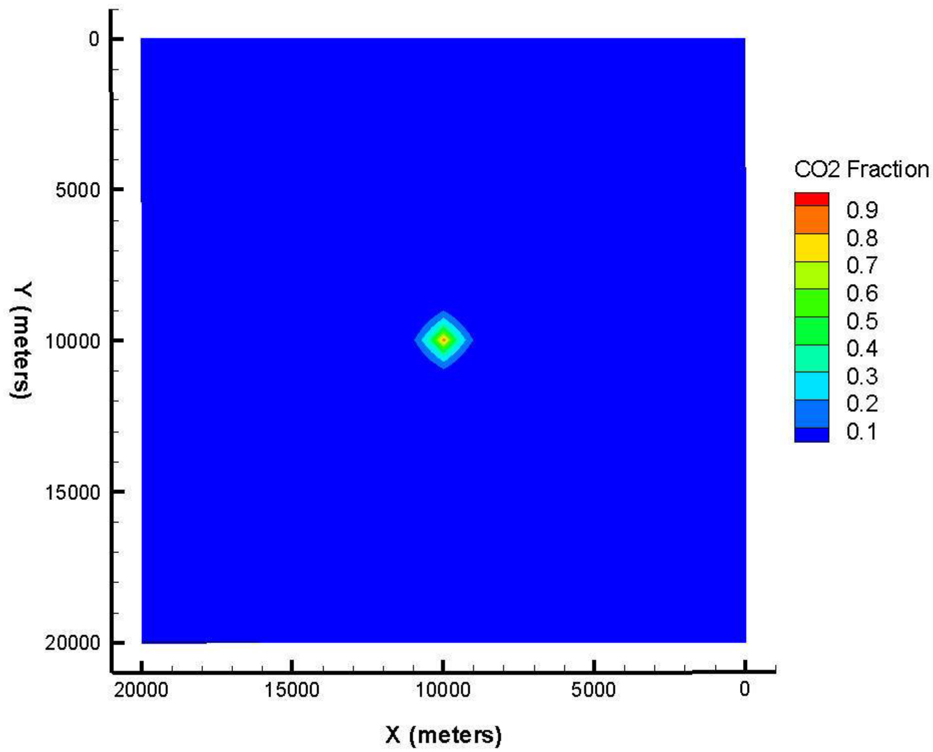
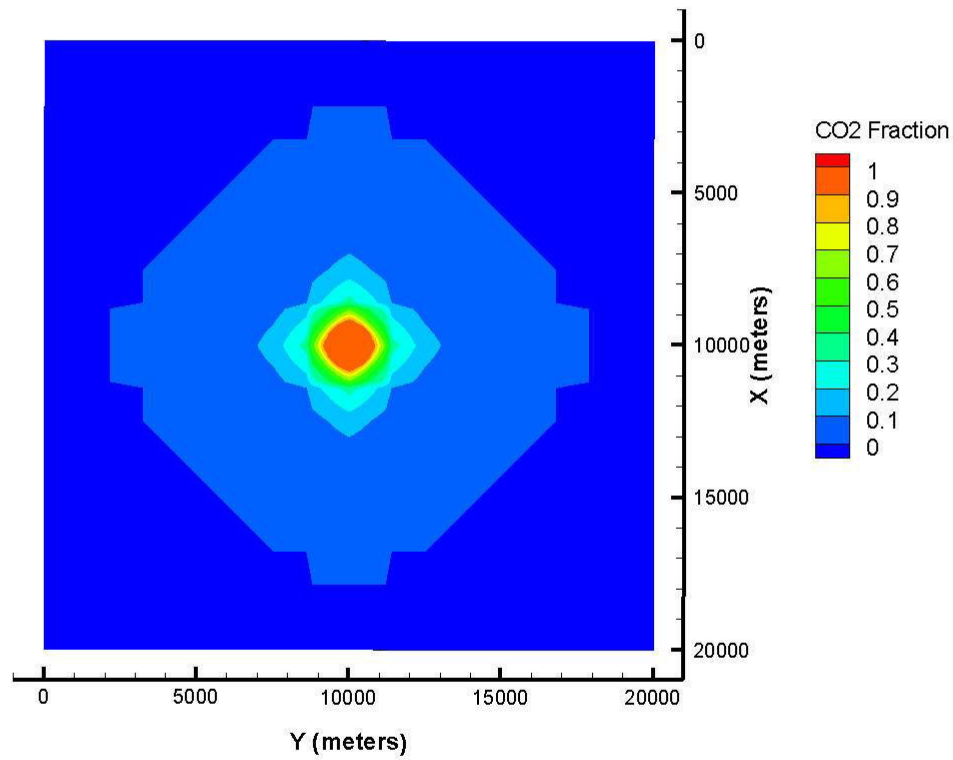
Top aquifer CO_2 Distribution (50 years)

Mean Log (Perm): -13,
Variance Log (Perm): 1



Mean Log (Perm): -14,
Variance Log (Perm): 0.2



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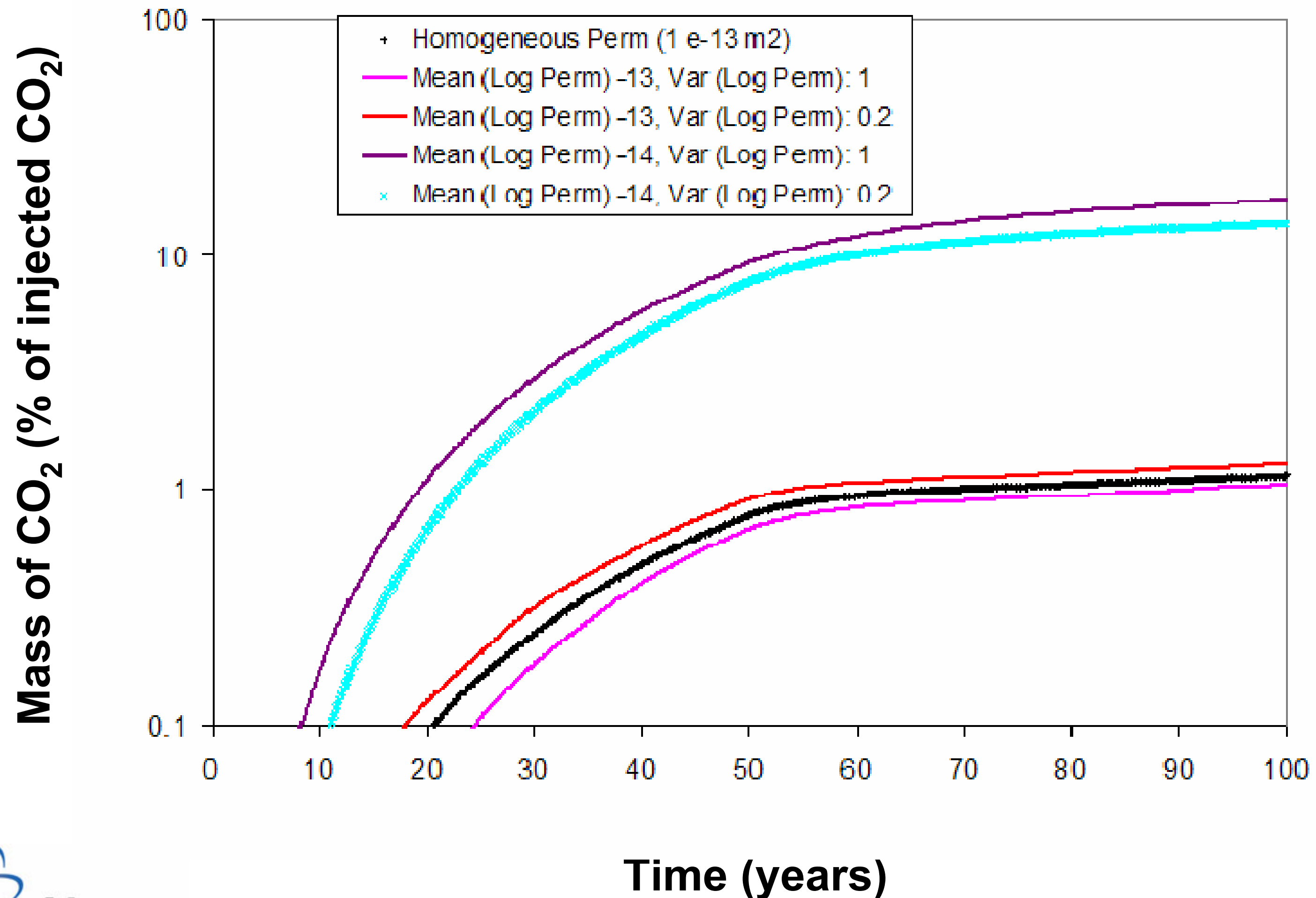
Effect of permeability heterogeneity on mass of CO_2 in top aquifer



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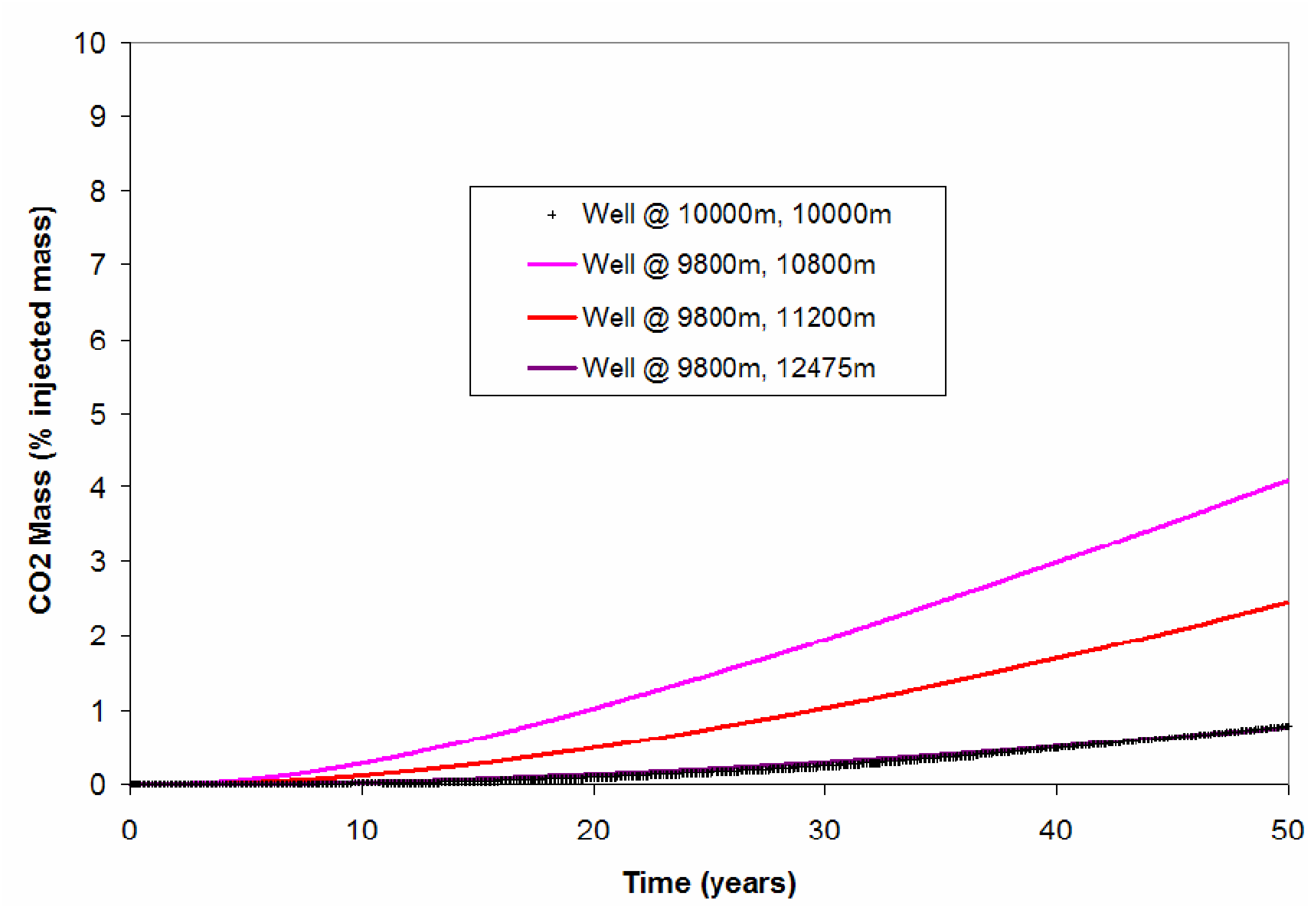
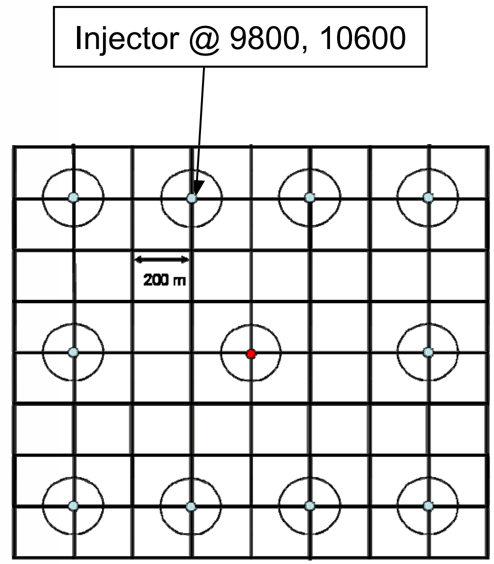
Effect of plugged wellbore location on mass of CO_2 in top aquifer





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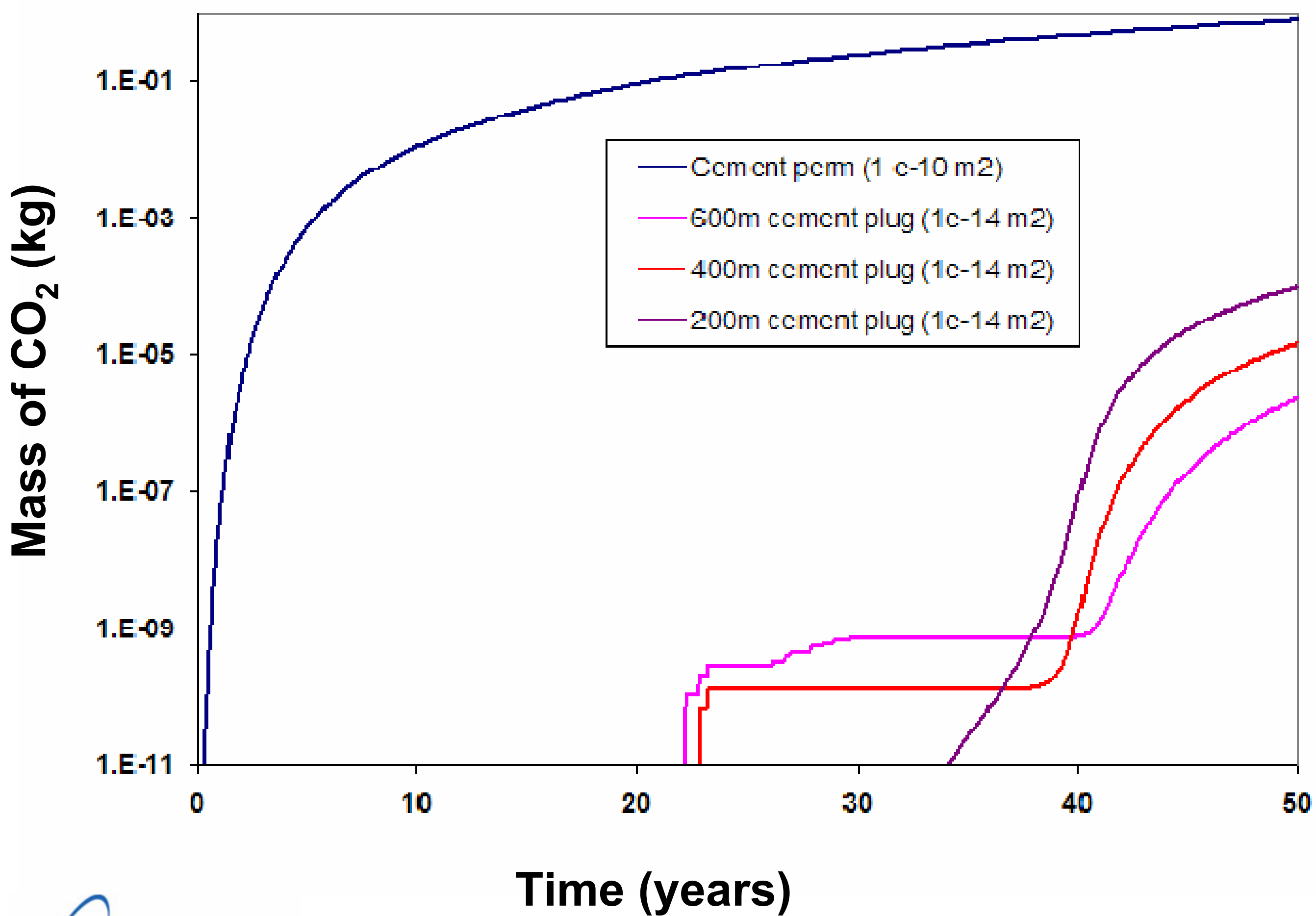
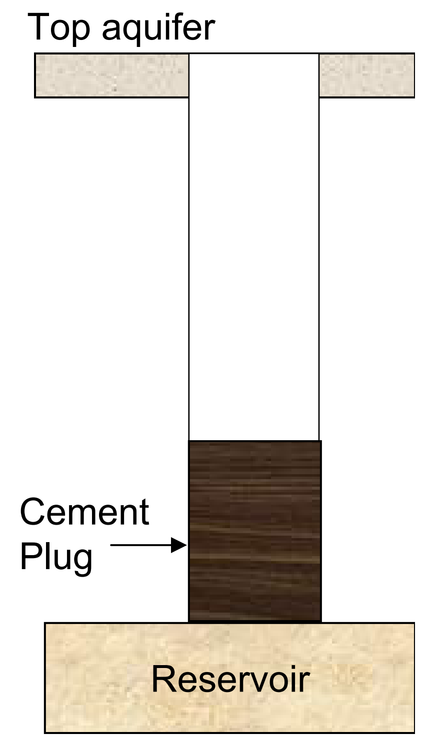
Effect of cement plug dimension on mass of CO_2 in top aquifer





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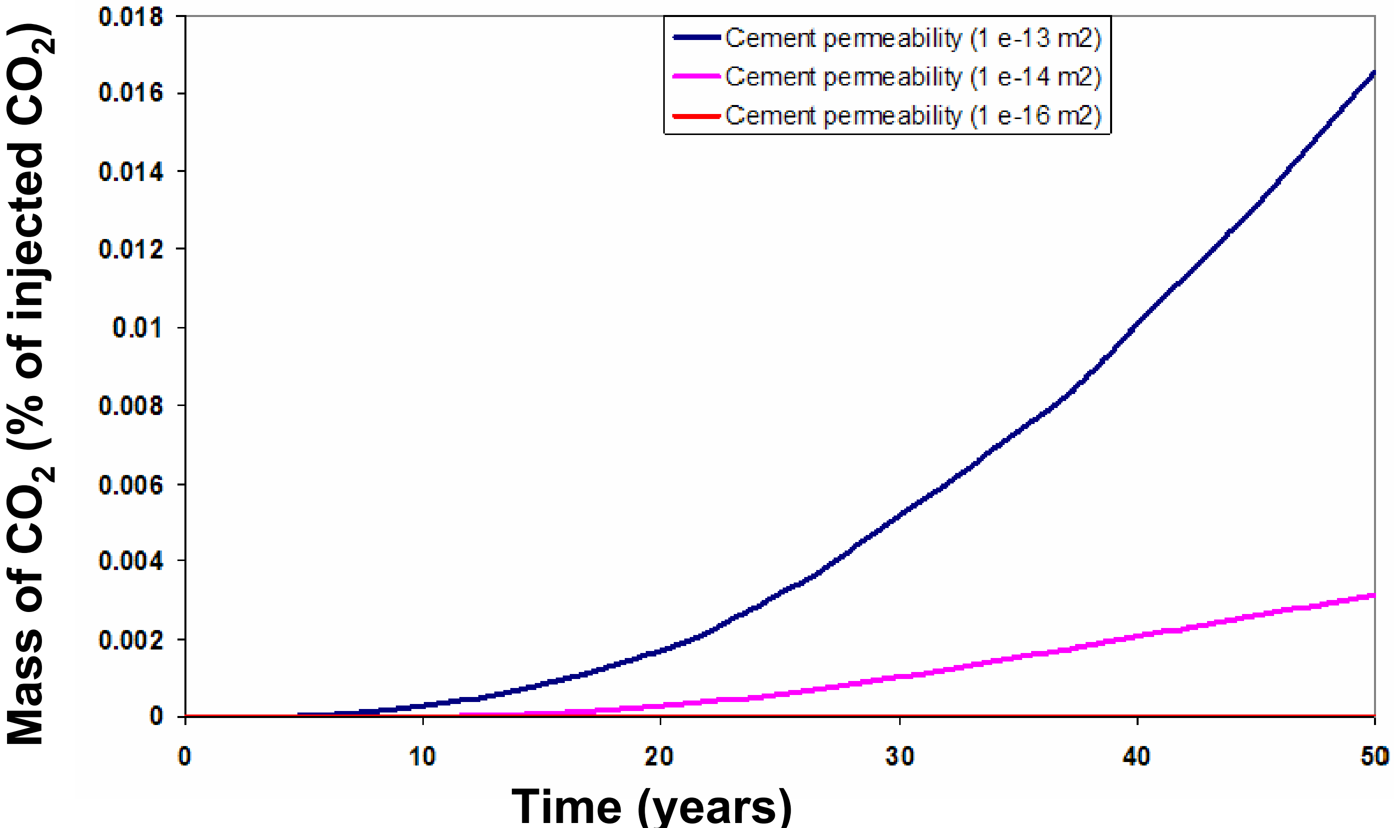
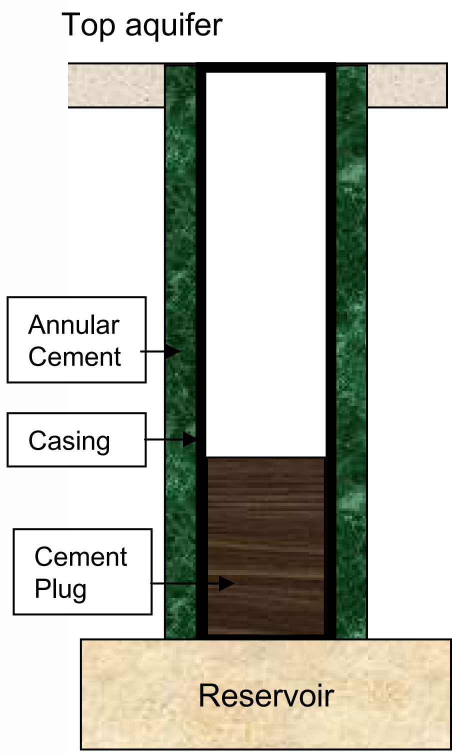
Simulating detailed well-completions





Embedded wellbore patch
Wellbore radius: 40 cm
Outer patch radius: 10 m
11 radial elements

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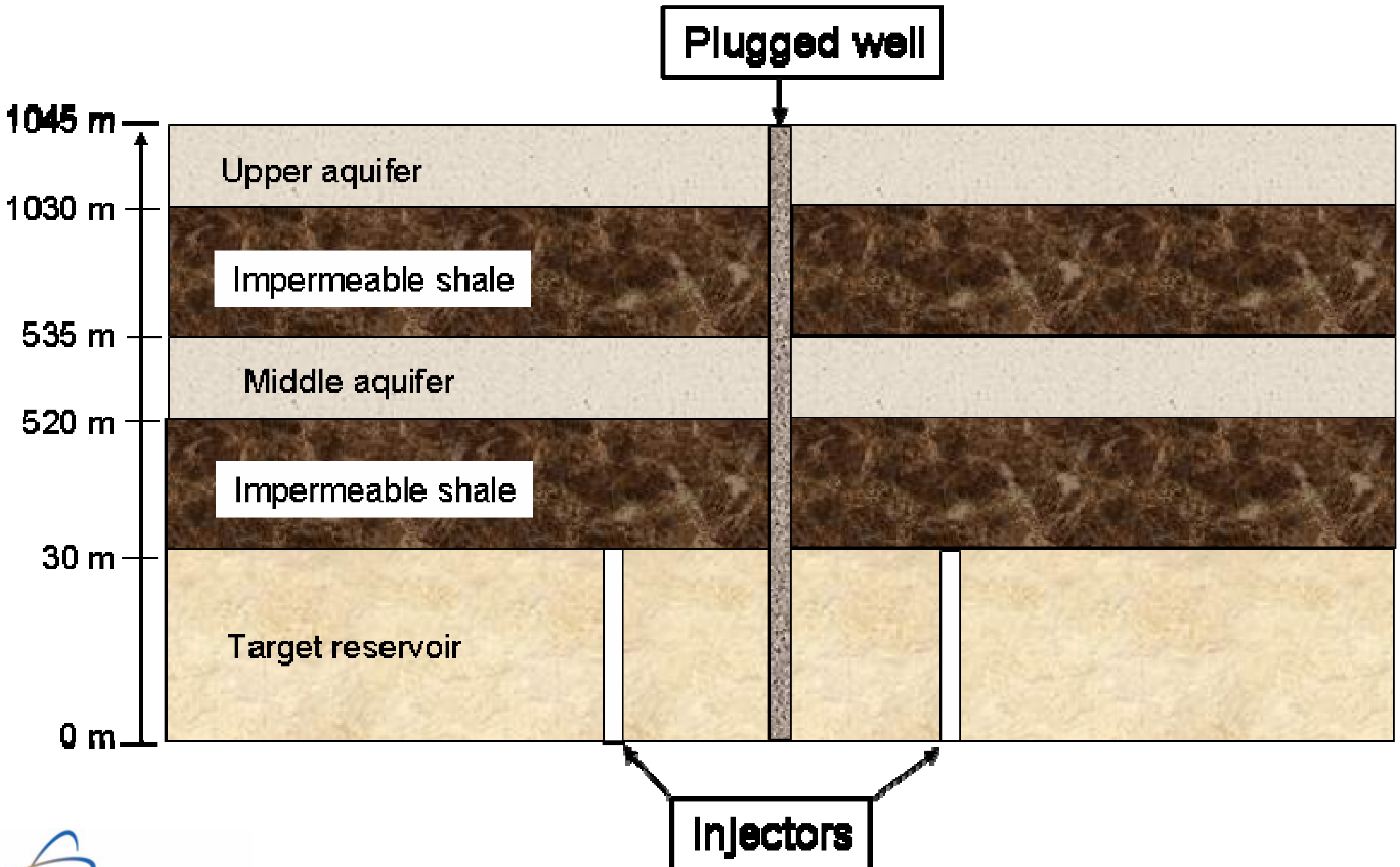
What impact does an additional aquifer have?



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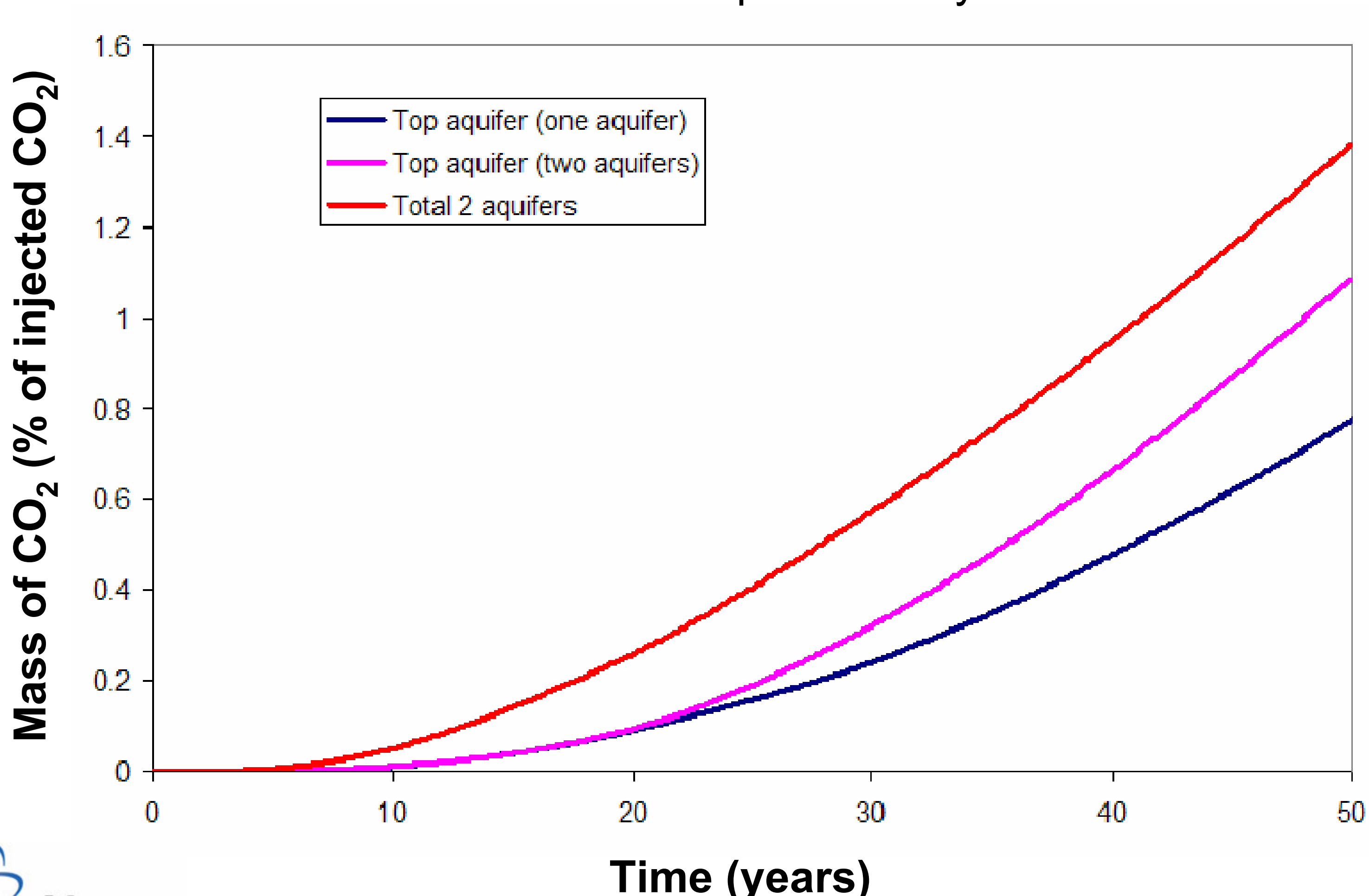
Time dependent mass of CO_2 in upper aquifers

Wellbore cement permeability: 10^{-10} m^2



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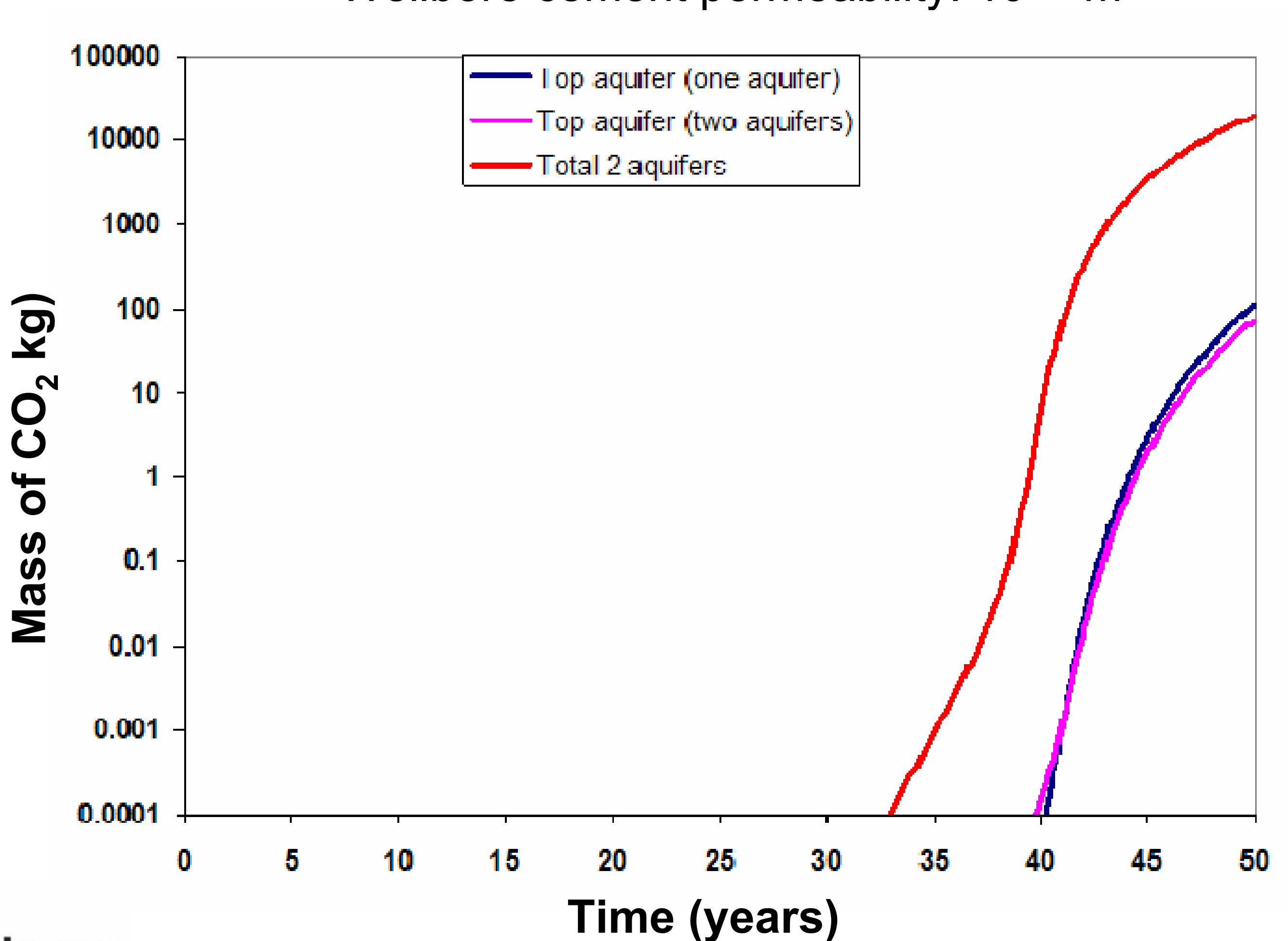
Time dependent mass of CO_2 in upper aquifers

Wellbore cement permeability: 10^{-14} m^2



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Conclusions

- Impact of cemented wellbores on overall system performance of large-scale injection operations needs to be characterized
- Numerical simulations capturing the details of wellbore geometry and dynamic evolution of near-wellbore conditions in a coarse large-scale grid are required
- We have developed numerical capabilities that can be used to simulate detailed wellbore/near-wellbore behavior in a large-scale sequestration operation

Acknowledgements

This work was funded by DOE through ZERT program

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